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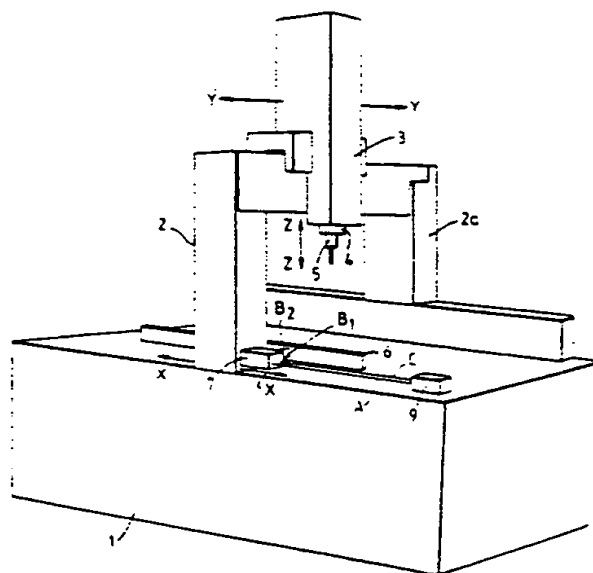
## Published

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(54) Title: OPTICAL APPARATUS FOR USE WITH INTERFEROMETRIC MEASURING DEVICES

## (57) Abstract

A laser interferometer system is disclosed which is able to make measurements of any deviations in the movement of a machine component which is moving along a main movement axis. The system can measure roll, pitch, yaw, straightness, and parallelism of two tracks using a single laser beam. Fig. 1 shows an arrangement for measuring roll of a vertical machine column (2) during movement of the column along the x-axis of a machine. A straight mirror (6) is positioned on the machine bed with its longitudinal axis aligned with the x-axis, and its reflecting surface normal to the x-axis. An optical component including a polarising beam splitter is mounted for movement with the machine column and generates from a laser beam (A), a measuring beam (B1) and a reference beam (B2) both directed at the mirror, but laterally separated in the direction of the Z axis. The reflected beams from the mirror are re-combined in the optical device to form a return beam (C) directed towards a detector adjacent the laser (9). Any change in relative length of the beams (B1) and (B2) give a measure of roll. Yaw can be measured by producing beams (B1) and (B2) laterally separated in the direction of movement, i.e. along the x-axis. Straightness is measured using a fixed length reference arm within the optical device. Parallelism is measured by taking straightness measurements of both pillars (2) and (2a). Pitch can be measured by producing four beams.



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**OPTICAL APPARATUS FOR USE WITH INTERFEROMETRIC MEASURING DEVICES.**

5 The present invention relates to optical apparatus for use with interferometric measuring devices. In particular, the invention relates to optical apparatus for measuring deviations in the movement of a machine component during movement thereof along its main movement axis with an interferometric measuring device.

10

Deviations in the movement of a machine component along its main movement axis generally involve rotation of the component about one or more axes of the machine, usually referred to as the x,y and z axes, and are referred to as pitch, roll and yaw errors. There are also errors in straightness of the movement which involve lateral deviations of the machine component from the main movement axis.

20 For the purposes of this specification, assuming that the machine component is moving along the x axis as its main movement axis,

"roll" is defined as rotation of the component about an axis parallel to the x axis,

25 "pitch" is defined as rotation of the component about an axis parallel to the y axis, and

"yaw" is defined as rotation of the component about an axis parallel to the z axis.

30 Throughout this specification the reference to a light beam should be interpreted to mean a beam having a wavelength in the range from infra-red, through visible to the ultra violet part of the spectrum.

35 In accordance with the present invention optical apparatus for measuring deviations in the movement of a machine component during movement thereof along its main movement

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axis comprises,

an optical device and a straight mirror, one of which is attached to the machine component, the other of which is mounted on a fixed part of the machine whereby relative  
5 movement is established therebetween during movement of the machine component,

said mirror having a longitudinal axis which is arranged to be parallel to the main movement axis of the machine component so that its reflecting surface faces in  
10 a direction normal to the main movement axis of the machine component,

means for generating at least one light beam directed towards the optical device,

and wherein the optical device includes means for  
15 generating from said at least one light beam, a measuring beam directed orthogonally towards the reflecting surface of the mirror on a first path, and a reference beam,

means being provided for interferometrically determining any variation in the path length of the  
20 measuring beam in relation to that of the reference beam.

The invention also includes methods of measuring roll, straightness, parallelism, pitch and yaw of the machine component as defined in the appended claims.

25

Examples of the invention will now be more particularly described with reference to the accompanying drawings in which:

Fig. 1 illustrates schematically the principle used  
30 by the invention for measuring roll of a machine component in one direction of movement thereof.

Fig. 2 is an illustration of one embodiment of an optical device for use on the machine shown in Fig. 1 showing the paths of the various light beams through the  
35 device.

Fig. 3 is a plan view in the direction of the arrow A of Fig. 2.

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Fig. 4 is an end view in the direction of the arrow B of Fig. 2.

Fig. 5 is a plan view of an alternative optical component for use with the machine of Fig. 1.

5 Fig. 6 is an elevation of the optical component of Fig. 5.

Fig. 7 shows a modification to the optical device of Fig. 4.

Fig. 8 is a plan view of an alternative optical  
10 device for measuring straightness of the movement of a machine component,

Fig. 9 is a plan view of a further alternative optical device for measuring yawing movements of a machine component, and

15 Fig. 10 is a plan view of the machine showing the positioning of the mirror and optical device for measuring parallelism of two tracks of the machine.

Referring now to Fig. 1 of the drawings there is shown a measuring machine having a fixed work-table 1, and movable  
20 components including a vertical columns 2, 2a having a main axis of movement in the direction x-x, a carriage 3 mounted on the column 2 and having a main axis of movement in the direction y-y, and a spindle 4 supported on the carriage 3 and having a main axis of movement in the  
25 direction z-z. The spindle 4 supports a measuring probe 5 for determining the position of a workpiece (not shown) which is placed on the worktable 1.

During measurements of a workpiece the movements of the  
30 various machine components are subject to errors in that the movable machine components can suffer deviations such as rolling, pitching and yawing movements about their main axes of movement.

35 Although various methods have been described for measuring such deviations, for example in US Patent No.s 3,654,446, 3,790,284, 4,261,107, measurement of errors due to the

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rolling movements of the machine component are the most difficult to obtain accurately by interferometric methods and the systems employed for such measurements are relatively expensive.

5

The apparatus employed by the present invention enables inter alia, direct measurements of rolling movements to be obtained with high accuracy and with little complexity using a single interferometer. This is achieved by using  
10 an optically straight mirror 6 mounted on a fixed part of the machine, e.g. the worktable, mounting an optical device 7 on the movable machine component being measured, directing two light beams  $B_1$  and  $B_2$  at the mirror 6 from the optical device 7, and receiving the return beams  
15 reflected from the mirror in the optical device, whereby any difference in the path length of the two beams due to rolling motion of the machine component can be determined interferometrically. One of the beams, say  $B_1$ , can be regarded as a measuring beam, while the other,  $B_2$  is the  
20 reference beam.

As can be seen from Fig. 1, roll of the vertical column 2 about its main axis of movement x-x will cause rotation of the optical device 7, thereby respectively increasing the  
25 path length of one of the light beams and decreasing the path length of the other. The light beams  $B_1$  and  $B_2$  are derived from a laser 9 mounted statically on, or adjacent to, the machine worktable, and which directs a single beam A towards the optical device 7. A return beam C from the  
30 optical device 7 is received by a detector (not shown) adjacent the laser.

Referring now to Figs. 2 to 4 of the drawings the optical device 7 comprises in combination, a polarising beam  
35 splitter and periscope unit 10, a polarising cube beam splitter unit 12, a retro-reflector unit 14 and a quarter wave plate 16.

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- The laser beam A is directed towards the unit 10 where at a first beam splitting surface 20 a first portion 22 of the beam is transmitted to the unit 12, and a second
- 5 portion 24 is reflected at right angles towards an inclined reflecting surface 26. At the surface 26 beam portion 24 is reflected into unit 12 in a direction parallel to beam portion 22.
- 10 Since the beam splitting surface 20 polarises the beam A into two orthogonal polarisation states, the transmitted beam portion 22 is next passed through a half-wave plate 30 (Fig. 4) to change its polarisation state to that of the reflected beam portion 24.
- 15 Beam portion 22 next passes to a second polarising beam splitting surface 28 in unit 12 where it is reflected towards the mirror 6 and through the quarter wave plate 16. At mirror 6 the beam portion 22 is reflected back and
- 20 passes again through the quarter wave plate 16. Having passed twice through the quarter wave plate 16 the polarisation state of beam portion 22 is such that on arrival at the beam splitting surface 28 it is transmitted to the retro-reflector 14. Retro-reflector 14 returns the
- 25 beam portion 22 to the mirror 6 on a parallel track through the beam splitting surface 28 and the quarter wave plate 16, and the mirror 6 reflects it back through the quarter wave plate 16 to the beam splitting surface 28. After its two further passages through the quarter wave
- 30 plate 16 the beam portion 22 is reflected at the beam splitting surface 28 and is directed back towards the unit 10.
- In order to avoid further reflection at the beam splitting
- 35 surface 20 the beam portion 22 is passed once again through the half wave plate 30 to change its polarisation state so that it will be transmitted through the beam

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splitting surface 20 and will leave the optical device 7 as outgoing beam C on a path parallel to, but displaced from, the incoming laser beam A.

5 The reflected beam portion 24 on leaving the reflecting surface 26 follows a similar path to that of the transmitted beam portion 22 except that it does not pass through the half wave plate 30. Thus the paths of the beam portions 22 and 24 exactly parallel each other  
10 through unit 12 to the mirror 6, the arrangement being such that after leaving unit 12, the beam portion 24 is deflected by the two beam splitting surfaces 26, 20 of the periscope to be combined with beam portion 22 so that the beam C leaving the optical device 7 is a composite beam.

15 It can be seen therefore that if the total path lengths of the two beam portions 22 and 24 between the beam splitting surface 28 and the mirror change, due to roll of the optical device about the axis x-x, the beam portions 22  
20 and 24 of the composite beam B will be phase shifted and be capable of producing interference fringes which can be detected. Beam portions 22 and 24 respectively form the beams B1 and B2 of the measuring and reference arms of the interferometer referred to above. Thus the composite  
25 beam C is directed into an appropriate fringe detection system (many types of which are available), which gives an output in dependence upon the fringe count as the machine moves. Since the fringe count is directly related to the amount of roll of the moving machine component, the  
30 machine readings can be corrected either in real time or stored and corrected later.

The optical device described above may be modified in a simple manner to enable yawing movements of the pillar to  
35 be measured. All that is required is to mount the combined beam splitter and periscope device 10 and the roof top reflector 14 in a position at right angles to

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that shown, so that the beams B1 and B2 instead of being vertically displaced, as shown in Fig. 1 to 4 become horizontally displaced. Then it can be seen that rotation of the optical device about the z axis will cause a  
5 variation in path length of beam B1 compared to beam B2, and this can be detected by creating interference fringes from the combined return beam in known manner.

The above described embodiment, although using several  
10 relatively expensive optical components, will provide high accuracy in its readings. Pitching and yawing motions of the vertical column will not affect the path length of the two beam portions being measured, although some deflection of the beams will take place. Provided that these  
15 deflections are small they can be accommodated by the optical device. Similarly any unforeseen deviations in the movement of the vertical columns in the x,y and z directions will not affect the path length differential of the beams.

20 Although the retro-reflector illustrated in the optical device of Figs. 1 to 4 is a roof top prism, it will be understood that it could be replaced by a pair of corner cube reflectors at a known distance apart. This will  
25 further reduce or eliminate any errors in the roll or yaw movements if the beam A impinges on the optical device in a direction which is not parallel to the direction of the axis of motion x-x.

30 A less expensive optical device which also performs in accordance with the invention is shown in Figs. 5 and 6. In this embodiment the polarising beam splitter unit 12 and the retro-reflector unit 14 of the embodiment of Figs. 2 to 4 are replaced by a single plane mirror. This also  
35 allows for the quarter-wave plate 16 to be eliminated. The result is that the returning composite beam C is co-incident with the incoming laser beam A and may



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interfere with the operation of the laser. Lateral displacement of the incoming and return beams is achieved with a second beam splitting and periscope unit, in order to separate the return beam for use in the detectors.

5

Referring now to Figs. 5 and 6 components of the alternative device which are identical to those of Fig. 1 are given the same reference numerals.

10 The incoming laser beam A passes through a non-polarising beam splitter and periscope unit 40 and the transmitted beam portion 42 passes to the polarising beam splitter and periscope unit 10. The reflected beam portion 42a passes out of the apparatus and is lost.

15

As in the embodiments described in Figs. 2 to 4, the transmitted beam portion 42 is split at the surface 20, a further transmitted beam portion 43 passing to the plane mirror 44 by means of which it is deflected towards the mirror 6 which in turn reflects it back along its path to the surface 20.

The reflected beam portion 46 is deflected by the periscope along a parallel path to a second plane mirror 48 (or to a second portion 48 of the same plane mirror 44) and is deflected to mirror 6 and back again through the periscope to surface 20 where it re-combines with the transmitted portion 43 of the beam to form combined beam C.

30

The combined beam C travels back towards the laser and is split by the beam splitter and periscope unit 40 to provide a deflected beam portion 50 which is directed into a detector system to generate and count any interference fringes caused by rolling movements of the optical device in the same manner as described above with respect to the embodiment shown in Figs. 2 to 4. The beam portions 42

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and 46 in this embodiment therefore form the beams  $B_1$  and  $B_2$  of the measuring and reference arms of the interferometer.

- 5 Clearly other modifications may be made to the above described optical components while achieving the same result. For example, the retro-reflector 14 is shown as a roof-top prism but it may be replaced by a pair of corner cube reflectors in known manner. Also the unit 40 need  
10 not be part of the optical device but may be positioned within or close to the laser.

Another modification of the embodiment shown in Fig. 4 is shown in Fig. 7. In this modification the second  
15 reflecting surface 26 of the periscope is deleted and replaced by a polarising beam splitting surface equivalent to surface 28 and arranged to reflect the beam towards the mirror 6 at points P1 and, after reflection from retro reflector 14, at P2 as shown. Such an arrangement would  
20 however be sensitive to any inaccuracies along the length of the mirror since the two beams  $B_1$  and  $B_2$  will now impinge on the mirror at two different points along its length. The advantage of this arrangement however is that the reference and measuring beams pass through the same  
25 amount of glass and the arrangement is more symmetrical.

Referring now to Fig. 8 there is shown another modified version of the optical device of Figs. 2 to 4 capable of measuring the straightness of the movement of the vertical  
30 machine column 2 along the direction x-x.

The optical device is made up of a polarising beam-splitting cube 60 and two retro-reflectors 62 and 64 on adjacent sides of the cube 60. A quarter wave plate 66  
35 is placed between the cube 60 and the straight mirror 6 on the opposite of the cube from the reflector 62.

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In this arrangement an incoming laser beam A is split at a beam splitting surface 68 of the cube, the reflected part of the beam 70 being directed towards the mirror 6, and after passing through the quarter wave plate 66 is  
5 reflected from the mirror 6 and passes once again through the quarter wave plate 66 to the beam splitting surface 68. Having passed twice through the quarter wave plate 66 the polarisation state of the beam is such that it is now transmitted at the beam splitting surface 68 and is  
10 reflected back via the retro-reflector 62 to the mirror 6 as beam 70A passing through the beam splitting surface 68 and the quarter wave plate on the way. After being reflected from the mirror the beam 70A passes a second time through the quarter wave plate 66 so that its  
15 polarisation state is now such that it is reflected at the beam splitting surface 68 and leaves the optical device as part of the outgoing beam C.

The beams 70,70A form the beam B1 of the measuring arm of  
20 an interferometer and, since the mirror is straight any lateral movement of the device while moving in the direction x-x will cause a change in the path length of the beams 70,70A.

25 The portion 72 of the incoming beam A which is transmitted through the beam splitting surface 68 is reflected around the retro-reflector 64. This portion 72 of beam A forms the beam B2 of the reference arm of the interferometer, and is combined with the measuring beam B1 at the beam  
30 splitting surface 68 to form a composite outgoing beam C.

If there is any straightness error in the movement of the optical device, the total length of the beams 70 and 70A will change and there will be interference of the  
35 measuring beam and reference beam parts of the composite beam C which can be detected in the detector and measured.

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Referring now to Fig. 9 there is shown a beam path diagram for an optical device which will measure yawing movements of the vertical machine column 2 as it moves along the direction x-x using the same laser and mirror positions as shown in Fig. 1. This optical component includes a polarising beam splitter 80 together with a retro-reflector 82, a quarter wave plate 84, a polarising beam splitter 86 and retro-reflector 88.

As described with reference to the earlier embodiment an incoming laser beam A is split at a polarising beam splitting surface 90 of the beam splitter 80 into reflected and transmitted components 92 and 94 respectively. The reflected component 92 travels through the quarter wave plate 84 to the mirror 6 and back to the beam splitting surface where its polarisation state enables it to be transmitted to the retro-reflector which returns it on a laterally spaced parallel path back to the mirror and to the beam splitter. Due to its two further passages through the quarter wave plate 84 it is finally reflected at the beam splitting surface 90 and leaves the device as a returning beam C.

The transmitted component 94 however, passes through a half wave plate 96 to a second polarising beam splitting surface 98 where, in parallel with the reflected component 92 it is reflected through the quarter wave plate 84 to the mirror, back to the retro-reflector where it is laterally displaced, back to the mirror 6 and back along its incoming path to be re-combined at the beam splitting surface 90 with the reflected component 92 to form a composite returning beam C.

It can be seen that yawing movements of the vertical machine column which rotate the optical device about the axis z-z will cause the path of one of the reflected or transmitted components 92, 94 of beam A to increase while

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the other one decreases. This differential change in the two path lengths will give rise to interference in the composite return beam C which can be detected and the deviation measured.

5

By suitable relative positioning and orientation of the optical devices and the straight mirror 6 described above, pitching movements of the vertical column can be measured and, the pitching, rolling, yawing and straightness  
10 deviations of the carriage 3 when moving along its axis z-z, and of the cross member 4 when moving along its axis y-y can also be measured interferometrically.

The apparatus of the present invention can also be used to  
15 measure parallelism of two slideways of a machine, for example the slideways on which the vertical columns 2, 2a of Fig. 1 move in the direction x-x.

To measure parallelism the mirror 6 may be placed in a  
20 fixed position parallel to the slideways. The optical device is mounted first on one of the vertical columns to measure straightness of the movement of the column by any of the methods described above. Then the optical device is transferred to the other vertical column and the  
25 process repeated to determine the straightness of the second slideway. By comparing the readings from both operations it is possible to determine the parallelism i.e. the relative straightness between the two slideways.

30 This is diagrammatically illustrated in Fig. 10, which shows the mirror 6 positioned on the fixed machine structure and the optical device carried by column 2 as shown in Fig. 1 for making the measurement of the straightness of the movement of the column 2 along its  
35 main movement axis x-x. The position of the laser 9 and detector are as described with reference to Fig. 1 and the optical device 7 is as described with reference to Fig. 8.

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The straightness of the movement of column 2a along its track is measured by setting up the laser 9 and optical device 7 as shown in dotted lines. From the measurements taken the mean straightness of the movement of each column  
5 can be determined and thus the degree to which the two tracks are non-parallel can also be determined.

Thus by measuring the various deviation of the movements of the different machine components from their anticipated  
10 lines, the errors in the readings of the machine scales can be determined and the errors in the position of the probe as read from the scales of the machine due to the above described deviations in movement can be corrected.

15 In a further modification of the invention, the quarter wave plates disclosed may be dispensed with if the retro-reflectors are chosen with appropriate refractive indices to achieve total internal reflection of the light beams which will alter their polarisation states in known  
20 manner.

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## CLAIMS

1. Optical apparatus for measuring deviations in the movement of a machine component during movement thereof  
5 along its main movement axis comprises:

an optical device and a straight mirror, one of which is attached to the machine component, the other of which is mounted on a fixed part of the machine whereby relative movement is established therebetween during movement of  
10 the machine component,

said mirror having a longitudinal axis which is arranged to be parallel to the main movement axis of the machine component so that its reflecting surface faces in a direction normal to the main movement axis of the  
15 machine component,

means for generating at least one light beam directed towards the optical device,

and wherein the optical device includes means for generating from said at least one light beam, a measuring  
20 beam directed orthogonally towards the reflecting surface of the mirror on a first path, and a reference beam,

means being provided for interferometrically determining any variation in the path length of the measuring beam in relation to that of the reference beam.  
25

2. Optical apparatus according to claim 1 and in which the reference beam is a fixed length reference beam.

3. Optical apparatus according to claim 1 and in which  
30 means are provided for directing the reference beam at the mirror along a first path parallel to the first path of the measuring beam but laterally displaced therefrom.

4. Optical apparatus according to claim 3 and in which  
35 the reference beam is laterally displaced from the measuring beam in the direction of the main movement axis.

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5. Optical apparatus according to claim 3 and in which the reference beam is laterally displaced from the measuring beam in a direction perpendicular to the direction of the main movement axis.

5

6. Optical apparatus according to claim 3 and in which the means for directing the reference beam at the mirror along a first path parallel to the first path of the measuring beam comprises:

10 a first polarising beam splitter for producing a reflected beam constituting the measuring beam, and a transmitted beam orthogonal thereto, constituting the reference beam,

15 a periscope for deflecting one of said beams onto a path parallel to but laterally displaced the other, and, an inclined reflecting surface in the path of each of the beams to deflect them towards the mirror.

7. Optical apparatus according to claim 6 and in which 20 the inclined reflecting surface comprises a second polarising beam splitting surface.

8. Optical apparatus according to claim 7 and in which retro-reflecting means are provided for producing, in each 25 of the measuring and reference beams, two parallel beam portions laterally separated from each other.

9. Optical apparatus according to claim 8 and in which wave plates are provided in the beam paths of the 30 measuring and reference beams in order to change their polarisation states to allow transmission through, and reflection from the second beam splitting device.

10. Optical apparatus according to claim 9 and in which: 35 i) the transmitted beam from the first polarising beam splitter passes in sequence to a half-wave plate, the second polarising beam splitting surface, a quarter-wave



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plate, the mirror, said quarter-wave plate, the second polarising beam splitting surface, the retro-reflecting means, the second polarising beam splitting surface, said quarter wave-plate, the mirror, said quarter-wave plate,  
5 the second beam splitting surface, the half-wave plate and the first beam splitting surface,

ii) the reflected beam from the first polarising beam splitter passes in sequence to the periscope, the second  
10 polarising beam splitting surface, said quarter-wave plate, the mirror, said quarter-wave plate, the second beam splitting surface, the retro-reflecting means, the second polarising beam splitting surface, said quarter-wave plate, the mirror, said quarter-wave plate,  
15 the second beam splitting surface and the periscope, and in which:

iii) the reflected beam and the transmitted beam are recombined at the first beam splitting surface to form a  
20 return beam for receipt by a detector.

11. Optical apparatus according to claim 6 and in which the inclined reflecting surface is a plane mirror.

25 12. Optical apparatus according to claim 11 and in which a second beam-splitter and periscope unit is provided in the path of the combined return beam to provide lateral separation from the incoming laser beam.

30 13. Optical apparatus according to claim 12 and in which:  
i) the transmitted beam from the first polarising beam splitter passes in sequence to a half-wave plate, a plane mirror, the straight mirror, said plane mirror the half-wave plate, and the first polarising beam splitter,  
35

ii) the reflected beam from the first polarising beam splitter passes in sequence to the periscope, a plane

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mirror, the straight mirror, said plane mirror, the periscope and, the first beam splitting surface, and in which:

- iii) the reflected beam and transmitted beam are  
5 re-combined at the first beam splitting surface to form a return beam which is deflected by the second beam splitter and periscope unit towards a detector.

14. Optical apparatus according to claim 2 and in which  
10 the means for generating the measuring and reference beams comprises:

a polarising beam splitter for producing a reflected beam directed towards the straight mirror which constitutes the measuring beam, and a transmitted beam,  
15 which constitutes the reference beam,

a first retro-reflector in the path of the transmitted beam for returning the transmitted beam to the polarising beam splitter along a path laterally separated from its incoming path, and

- 20 a second retro-reflector for receiving the reflected beam from the straight mirror and for returning it along a path laterally separated from its incoming path.

15. Optical apparatus according to claim 14 and in which a  
25 quarter wave plate is provided in the path of the measuring beam between the polarising beam splitter and the straight mirror.

16. Optical apparatus according to claim 4 and in which  
30 the means for directing the reference beam at the mirror along a first path parallel to the first path of the measuring beam comprises:

a first polarising beam splitter for producing a reflected beam constituting the measuring beam, and a  
35 transmitted beam orthogonal thereto constituting the reference beam,

a second beam splitting surface for producing from the

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transmitted beam a reflected beam directed towards the mirror.

17. Optical apparatus according to claim 16 and in which a retro-reflector is provided in the paths of each of the measuring and reference beams after reflection from the mirror to produce lateral separation between the incoming laser beam and the outgoing combined beam.

18. Optical apparatus according to claim 17 and in which:

- i) the transmitted beam from the first polarising beam splitter passes in sequence to a half-wave plate, a second polarising beam splitter, a quarter-wave plate, the straight mirror, said quarter-wave plate, the second polarising beam splitter, the retro-reflector, the second polarising beam splitter, said quarter-wave plate, the straight mirror, the second polarising beam splitter, the half-wave plate, and the first polarising beam splitter,
- ii) the reflected beam from the first polarising beam splitter passes in sequence to a quarter-wave plate, the straight mirror, the quarter-wave plate, the first polarising beam splitter, the retro-reflector, the first polarising beam splitter, the quarter-wave plate, the straight mirror, the quarter-wave plate and the first polarising beam splitter, and in which,

- iii) the reflected beam and the transmitted beam are re-combined at the first polarising beam splitter to form a return beam for receipt by a detector.

19. A method of measuring deviations in the movement of a movable machine component during movement thereof relative to a fixed machine structure along a main movement axis comprising the steps of:

- mounting a straight mirror on one of the movable machine component and the fixed machine structure with

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it's longitudinal axis parallel to, and it's reflecting surface orthogonal to said main movement axis,

mounting an optical component on the other one of the movable machine component and the fixed machine structure  
5 whereby relative movement occurs between the optical component and the mirror when the machine component moves along the main movement axis,

directing a light beam to be incident on the optical component,

10 producing from the optical component a measuring beam and a reference beam, at least the measuring beam being directed towards the reflecting surface of the mirror at right angles thereto, the reference beam also being reflected by a reflector,

15 receiving the reflected measuring beam from the mirror and the reflected reference beam and combining them into a single return beam,

producing in one of the beams a polarisation state different to that of the other one of the beams before  
20 combining them into a single return beam,

directing the single combined beam into a detector for determining interferometrically any relative change in path lengths between the two beams, and,

providing a signal indicative of said relative change  
25 in path length.

20. A method according to claim 19 for measuring rolling movements of the machine component as it moves along the main movement axis and wherein the reference beam is also  
30 directed towards the mirror along a path parallel to the path of the measuring beam but separated therefrom laterally in a direction perpendicular to the main movement axis.

35 21. A method according to claim 19 for measuring yawing movements of the machine component as it moves along the main movement axis and wherein the reference beam is also

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directed towards the mirror along a path parallel to the path of the measuring beam but separated therefrom laterally in the direction of the main movement axis.

- 5 22. A method according to claim 19 for measuring the straightness of the movement of the machine component along the main movement axis and wherein the reference beam is directed over a fixed distance to a retro-reflector.

10

23. A method according to claim 22 for measuring the parallelism of two tracks on which machine components move comprises the further steps of:

- 15 measuring the straightness of a first track with one of the mirror and the optical device mounted on a machine component movable therealong,

re-positioning said one of the mirror and the optical device onto a second machine component movable along the second track,

- 20 measuring the straightness of the second track, and determining from the two straightness measurements the parallelism of the two tracks.

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Fig.3.

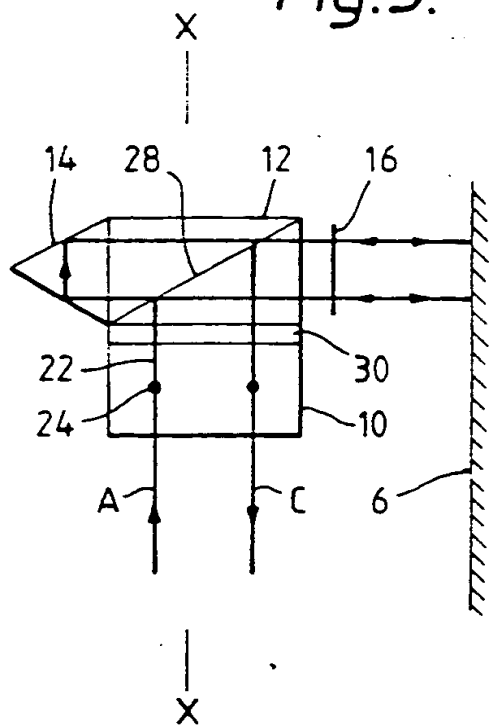


Fig.4.

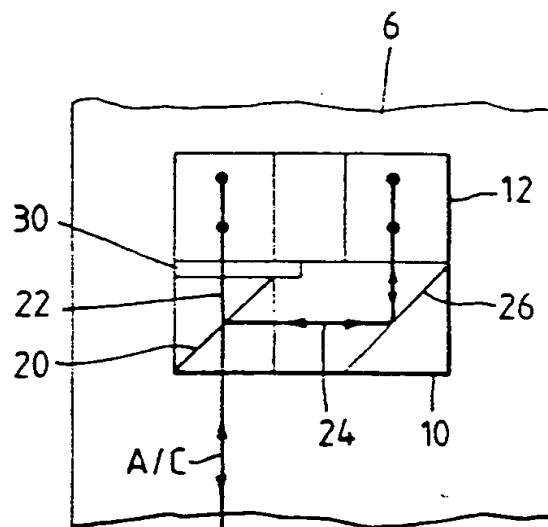


Fig.5.

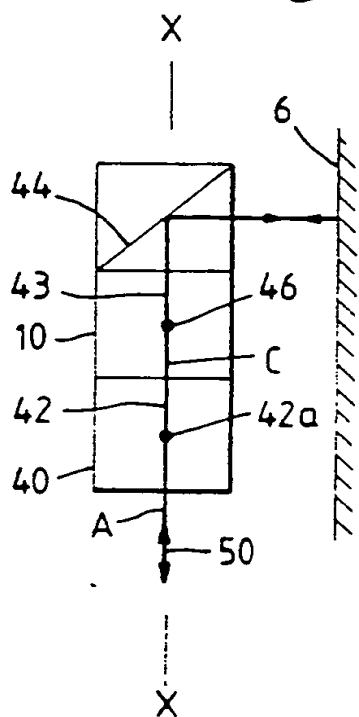
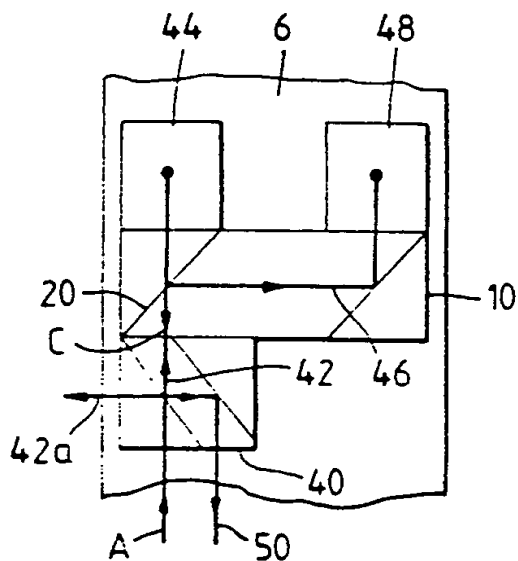


Fig.6.





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Fig.7.

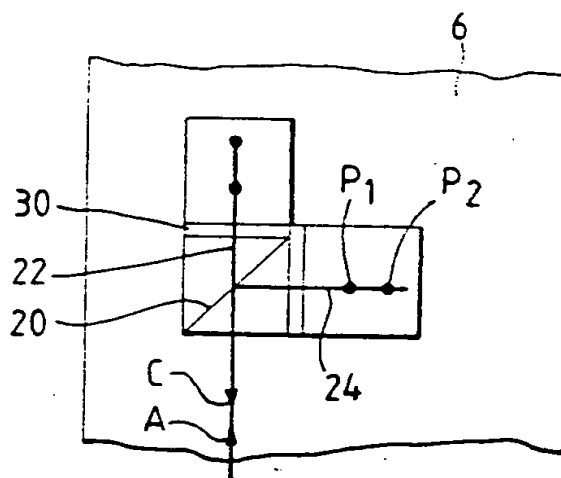


Fig.8.

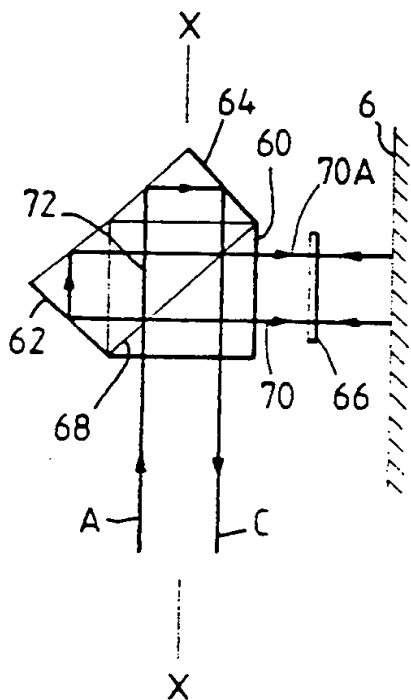
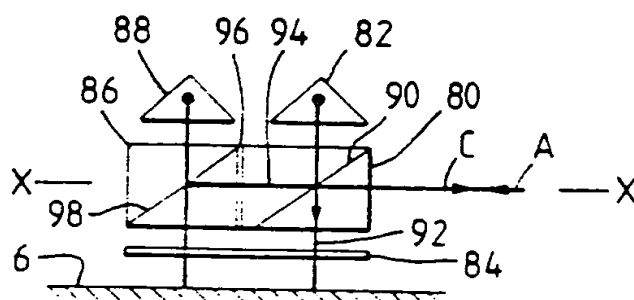
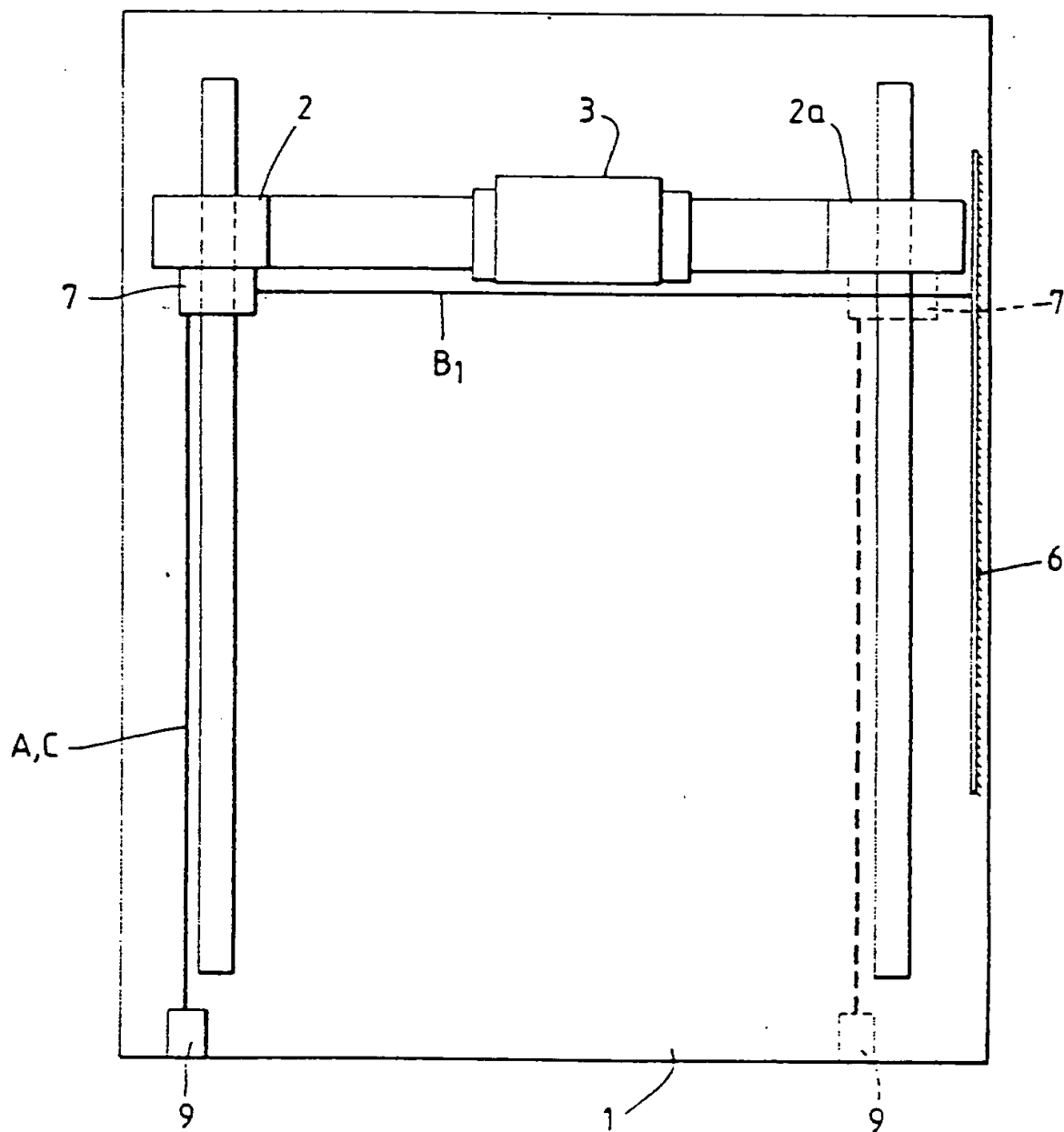


Fig.9.



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Fig.10.



SUBSTITUTE SHEET

# INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 88/01137

## I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC<sup>4</sup>: G 01 B 9/02; G 01 B 11/26; G 01 D 5/26

## II. FIELDS SEARCHED

Minimum Documentation Searched<sup>1</sup>

Classification System

Classification Symbols

IPC<sup>4</sup>                      G 01 B; G 01 D

Documentation Searched other than Minimum Documentation  
to the Extent that such Documents are Included in the Fields Searched<sup>2</sup>

## III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>3</sup>

Category <sup>4</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
A	Feinwerktechn. & Messtechn. vol. 85, no. 6, 9 August 1977 T.M. Hoffer et al.: "Abnahme von Werkzeugmaschinen mit einem Laser-Mess- system", pages 229-284, see pages 232-235	1,3-6,19-23
A	GB, A, 2121165 (M.R. HAMAR) 14 December 1983, see abstract; figures	1,3,4,21
A	US, A, 4498773 (ROCKWELL INT. CORP.) 12 February 1985, see column 2, line 59 - column 3, line 13; figures	1,3,19
A	GB, A, 2162942 (INDRA PUTRA ALMANAR) 12 February 1986, see figures; abstract	1,8,20,21
A	FR, A, 2088675 (THOMSON-CSF) 7 January 1972, see pages 6,7; figure	1,3,5,6,8, 11,20
A	FR, A, 2183908 (HEWLETT-PACKARD CO.) 21 December 1973, see the whole document	1

\* Special categories of cited documents: <sup>10</sup>

"A" document defining the general state of the art which is not  
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later than the priority date claimed

"T" later document published after the international filing date  
or priority date and not in conflict with the application but  
cited to understand the principle or theory underlying the  
invention

"X" document of particular relevance: the claimed invention  
cannot be considered novel or cannot be considered to  
involve an inventive step

"Y" document of particular relevance: the claimed invention  
cannot be considered to involve an inventive step when the  
document is combined with one or more other such docu-  
ments, such combination being obvious to a person skilled  
in the art.

"&" document member of the same patent family

## IV. CERTIFICATION

Date of the Actual Completion of the International Search

4th April 1989

Date of Mailing of this International Search Report

24.04.89

International Searching Authority

EUROPEAN PATENT OFFICE

Signature of Authorized Officer

P. G. VAN DER PUTTEN

## III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

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A	US, A, 3622244 (OPTOMECHANISMS, INC.) 23 November 1971, see the whole document --	1,3,6-9,12
A	US, A, 4261107 (CATERPILLAR TRACTOR CO.) 14 April 1981, see the whole document (cited in the application) --	1
A	DE, A, 1945487 (Fa. CARL ZEISS) 8 April 1971, see pages 4-6  -----	1,3,5,6

# ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

GB 8801137

SA 26160

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 14-04-89. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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